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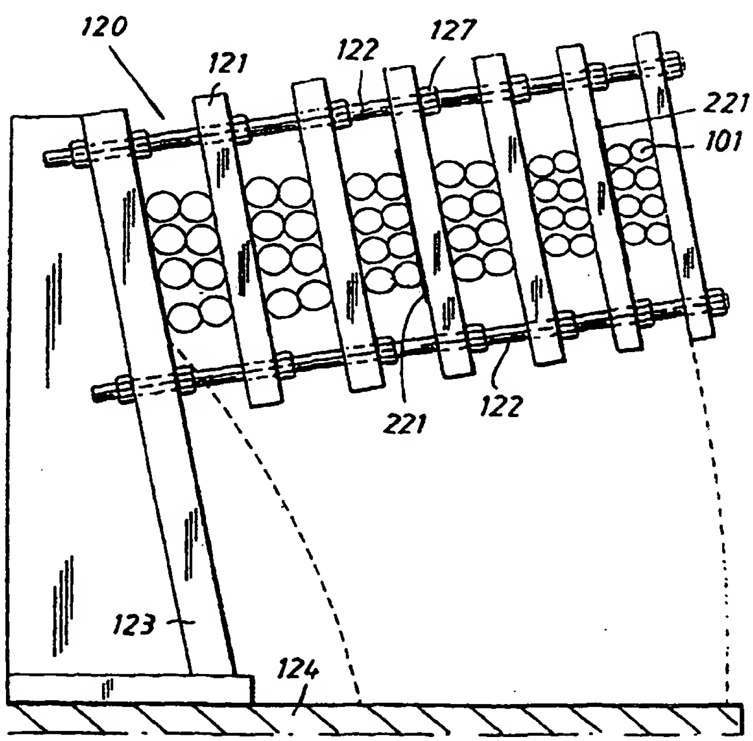
(54) Title: ROTATING ELECTRIC MACHINE AND A BRACING DEVICE FOR SUCH A MACHINE

(57) Abstract

The stator winding in a rotating electric machine is provided with a bracing device (120). The stator (106) has radial slots (111) to receive the winding cables (101). The winding forms layers at different radial distances from the air gap (108) between the rotor (107) and the stator (106). The part of a cable (101) that passes to and fro one through the stator (106) between different layers constitutes a coil (113) with an arc-shaped coil end protruding from each end surface (114) of the stator (106). The cable consists of high-voltage cable (101). The substantially radial and axial spaces (118 and 119, respectively) existing between the coils (113) contain an electrically insulating bracing device (120). The latter consists of plates (121) of non-conducting material that extend through axial spaces (119) between the coils (113) and are radially clamped to the coils (113) by means of bolts (122) of non-conducting material. The bolts (122) extend through radial spaces (118) and are secured in a bracing fixture (123) emanating, for instance, from the stator body (124).



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ROTATING ELECTRIC MACHINE AND A BRACING DEVICE FOR SUCH A MACHINE

The invention relates to a rotating electric machine of the type described in the preamble to claim 1 and to a bracing device for such a machine.

The present invention belongs to the area of rotating electric machines such as synchronous machines and dual-fed machines, applications in asynchronous static current converter cascades, outer pole machines and synchronous flow machines, and is intended for use at high voltages. High voltages shall be understood here to mean electric voltages in the first place in excess of 10 kV. A typical operating range for the machine according to the invention may be 36 to 800 kV.

The problem addressed by the invention has been accentuated in a high-voltage electric alternating current machine intended primarily as generator in a power station for generating electric power. Similar machines have conventionally been designed for voltages in the range 6-30 kV, and 30 kV has normally been considered to be an upper limit. This generally means that a generator must be connected to the power network via a transformer which steps up the voltage to the level of the power network, i.e. in the range of approximately 130-400 kV.

Normally all large generators are provided with two-layer windings and coils of the same size. Each coil is placed with one side in one layer and the other side in the second layer. All coils thus cross each other in the coil ends. According to conventional technique,

the stator windings are relatively stiff and are connected at the coil ends.

A conductor is known through US 5,036,165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US 5,066,881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

The object of the present invention relates to a rotating electric machine for high voltages. According to the invention, the winding consists of high voltage cables.

In such high-voltage machines the stator slots in which the coils are situated are considerably deeper and typically have 10-12 or up to 18, and in certain cases even more winding layers. The number of coil ends is thus large, with many intersections. This not only confuses the winding operation and makes for bulky coil-end packages that may protrude into the air gap between stator and rotor, but also increases the risk of wear at all intersection points between the coils since they vibrate during operation.

More specifically, the object of the present invention is to solve this problem of the large coil-end packages and minimize wear between the winding coils. This ob-

ject is achieved by giving the stator winding according to the invention the features defined in the characterizing portion of claim 1.

By the bracing means, a sufficient fixation of the coil end arcs of the high voltage cable is attained.

According to a preferred embodiment of the invention, the fixation is such that the coil end arcs are maintained outside the innermost part of the stator. Thereby the coil end arcs do not form an obstacle for the axial mounting of the rotor in the stator.

According to further preferred embodiments of the innovation, the bracing means are either conductive or insulating.

Further advantageous realisations of the construction of the bracing means are specified as advantageous embodiments of the invention in further dependent claims.

Further dependent claims also specify advantageous embodiments of the structure of the cable as discussed below.

By using high-voltage insulated electric conductors, in the following termed high-voltage cables, with solid insulation similar to that used in cables for transmitting electric power (e.g. XLPE cables) the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The conventional step-up transformer and a high-current breaker can thus be eliminated, resulting in lower total plant cost.

The invention is in the first place intended for use with a high-voltage cable of the type built up of a core having a plurality of strand parts, an inner semiconducting layer surrounding the core, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer, and its advantages are particularly pronounced here. The invention refers particularly to such a cable having a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm^2. Such applications of the invention thus constitute preferred embodiments thereof.

With the device according to the invention the windings are preferably composed of cables of a type having solid, extruded insulation, such as those used nowadays for power distribution, e.g. XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more stand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when bent and when subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa.

The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at le-

ast of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently great to enclose the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface and the winding, with these layers, will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The invention will be explained in more detail in the following with reference to the accompanying drawings in which

Figures 1 shows a cross section through a cable used in conjunction with the invention,

Figures 2 shows part of one end of a stator with a plurality of coil ends protruding from its end surface, only a few of such coils having been drawn in,

Figure 3 shows in radial section one half of an alternating current generator with a stator winding according to the invention,

Figures 4 shows, seen radially from the air gap, a coil-end package in which a bracing device according to the invention is used,

Figure 5 shows the same coil-end package seen in axial direction towards the stator,

Figure 6 shows a bracing device according to the invention in axial section through a coil-end package,

Figure 7 shows a view from above of a plate included in the bracing device.

Figure 8 shows a schematic side view of parts of the machine, and

Figure 9 is a view similar to that of fig. 6, but showing a modified embodiment.

Figure 1 shows a cross section through a cable 101 used in the present invention. The cable 101 is composed of a conductor 102 having circular cross section and made of copper, for instance, and consisting of a number of strand parts. This conductor 102 is arranged in the middle of the cable 101 and around the conductor is a first semiconducting layer 103. Around the first semiconducting layer 103 is an insulating layer 104, e.g. XLPE-insulation, and around the insulating layer 104 is a second semiconducting layer 105. In this case, therefore, the cable does not include the outer protective sheath that normally surrounds such a cable for power distribution. The cable may be in the order of magnitude stated in the introduction.

Figure 3 shows a section taken diametrically through one half of a high-voltage generator with a stator 106, a rotor 107 with an air gap 108 between them. Figure 2 shows the inner surface 109 of the stator, facing towards the air gap 108. The stator 106 has inwardly directed stator teeth 110 defining between them radial slots 111 to receive winding cables 101. The winding thus forms a large number of layers through the deep slots 111 which, in the example shown, have place for

twelve cables, each in its own enlargement 112 in the slots 111. The term "layers of the winding" here refers to layers at different radial distance from the central axis of the stator. "Stratum", however, refers to strata of the winding at different axial distances from the end surfaces of the stator.

Figure 2 shows how the cable 101 forms coils 113 passing axially to and fro through the stator 106 and forming arc-shaped coil-ends outside the end surfaces 114 of the stator. A coil thus consists of a turn of the cable through the stator. A coil group comprises the winding for one phase. The part of a coil group situated in one and the same winding layer and whose coil-ends are situated in different strata is termed here a "coil group part".

Contrary to previously known multi-strata stator windings, the coils 113 according to the invention are arranged so that they do not cross each other in the same coil group part. Figure 2 shows a group part consisting in this case of four coils 113a, 113b, 113c and 113d, arranged to lie axially one outside the other with substantially coinciding centres. Since coil 113a has larger diameter than coil 113b, which in turn has larger diameter than coil 113c, which in turn has larger diameter than coil 113d, these coils do not cross or come into contact with each other. The number of slots 111 bridged by each coil before it enters the stator again thus varies within the group part. I.e. coil 113d bridges the least number of slots and coil 113a the greatest number of slots.

Winding is performed, furthermore, so that the cable in the coil at the transition from the first slot in one direction to the second slot in the opposite direction

changes places in the slot to the winding layer situated nearest to the adjacent one outside it. The situation is the same upon its return to the first slot.

An example of such a winding is revealed in Figure 4, showing the coil-end package seen radially outwards from the air gap between rotor and stator. As is clear, the coil group parts are in this case arranged so that alternate coil group parts 116 pass radially inside the next adjacent coil group 117. This winding, known as stepped lap winding, greatly reduces the radial extension of the coil-end package. Furthermore, as can be seen in Figure 4, radial spaces are formed. Figure 5, showing the axial end of the coil-end package, shows that axial spaces are also formed. These radial and axial spaces can be utilized in advantageous manner to brace the coil-end package in order to vibrations during operation, and thus wear between the cables in the end package.

In an axial section through a coil-end package Figure 6 shows a bracing device 120 according to the invention. It consists of plates 121 inserted through the axial spaces 119 between the coils 113. The plates 121 are supported and secured by two bolts 122 inserted in the radial spaces between the coils 113. The plates 121 and bolts 122 are made of electrically non-conducting material and are secured in a bracing fixture 123 emanating, for instance, from the stator body 124 or the pressure plates on the stator. The plates 121 are provided with two recesses 125, 126 to receive bolts 122. These recesses are open from the edge of the plate to allow them to be fitted around respective bolts 122. Assembly is facilitated since the recesses 125 and 126 are substantially perpendicular to each other. The plates 121 are compressed against the coils 113, one

after the other, with the aid of nuts 127 in threaded engagement with the bolts 122.

In order to prevent the cables being subjected to too high a surface pressure, cable against cable or cable against plate, an easily mouldable compound is inserted between the cables and between the cables and the plates. The compound is then cured and forms an element that distributes the pressure uniformly and prevents wear upon vibration. The compound may also be used to insulate the cables from each other, or alternatively to have a specific electrical contact with each other.

The invention is of course not limited to the stepped lap winding described above, but is applicable to any winding with axial and radial spaces.

Figure 8 illustrates schematically how the device according to the invention facilitates mounting of the rotor R into the stator S. The coil end arcs are shown as A in this figure. They are prevented by the bracing device from extending into the area X to the right of line L in the figure, but are maintained on the left side thereof. Thus, the rotor may be introduced into the stator in the direction of the axial arrow P without being obstructed by the coil ends A.

Figure 9 illustrates how a soft dampening layer 221 can be provided at the surface of the plates 121 and abutting the cables 101. The layer 221 is preferably conductive and may be grounded, e.g. by a grounding braid.

CLAIMS

1. A rotating electric machine having rotor, stator (106) and stator windings (101), the stator windings forming coil end arcs (113) at the axial ends of the stator (106), **characterized** in that the windings include high voltage cable (101) and that bracing means are provided at the coil end arcs (113) at at least one end of the stator (106) to attain fixation of the coil end arc (113).

2. A rotating electric machine according to claim 1, **characterized** in that the coil end arcs (113) at said at least one end are fixed to be located radially outside the innermost part of the stator (106).

3. A rotating electric machine according to claim 1 or 2, **characterized** in that the bracing means (120) form axial and radial spaces between the coil end arcs (113).

4. A rotating electric machine according to any of claims 1-3, **characterized** in that the bracing means (120) is electrically insulated and comprises plates (121) of non-conductive material.

5. A rotating electric machine according to any of claims 1-3, **characterized** in that the bracing means (120) is of electrically conductive material and comprises plates (121).

6. A rotating electric machine according to claim 4 or 5, **characterized** in that the plates (121) extend through axial spaces (119) between the coil end arcs (113) and are radially clamped to the coil end arcs

(113) by radial bolts (122) extending through radial spaces (118).

7. A rotating electric machine according to claim 6, **characterized** in that the bolts (122) are of non-conductive material.

8. A rotating electric machine according to claim 6, **characterized** in that the bolts (122) are of conductive material.

9. A rotating electric machine according to any of claims 6-8, **characterized** in that the bolts (122) are secured in a bracing fixture (123) emanating from the stator body 124.

10. A rotating electric machine according to any of claims 6-9, **characterized** in that the plates (121) are provided with at least two recesses (125, 126) to receive said bolts (122).

11. A rotating electric machine according to claim 10, **characterized** in that the number of recesses (125, 126) is two.

12. A rotating electric machine according to claim 10 or 11, **characterized** in that said recesses (125, 126) are open from the edge of the plate (121) to allow them to be fitted around each respective bolt (122), the recesses (125, 126) being substantially perpendicular to each other in order to facilitate assembly.

13. A rotating electric machine according to any of claims 1-12, **characterized** in that the stator (106) has radial slots (111) to receive the conductors (101) of the winding in layers at different radial distances

from the air gap (108) between the rotor (107) and the stator (106), wherein the part of a conductor (101) that passes to and fro once through the stator (106) between different layers constitutes a coil (113) with an arc-shaped coil end protruding from each end surface (114) of the stator (106) and wherein substantially axial and radial spaces (118 and 119, respectively) exist between the coils (113).

14. A rotating electric machine as claimed in any of claims 1-13, **characterized** by a pressure-distributing, wear-preventing, curable compound between the cables (101), and between the cables (101) and the plates (121).

15. A rotating electric machine as claimed in any of claims 1-14, **characterized** in that the high-voltage cable (101) comprises a core (102) having a plurality of strand parts, an inner semiconducting layer (103) surrounding the core (102), an insulating layer (104) surrounding the inner semiconducting layer, and an outer semi-conducting layer (105) surrounding the insulating layer.

16. A device as claimed in claim 15, **characterized** in that the high-voltage cable (101) has a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm^2.

17. A device as claimed in any of claims 15-16, **characterized** in that the winding is flexible and comprises an electrically conducting core surrounded by an inner semiconducting layer, an insulating layer of solid material surrounding the inner semiconducting layer, and an outer semi-conducting layer surrounding the

insulating layer, which layers are in contact with each other.

18. A device as claimed in claim 17, **characterized** in that said layers consist of materials with such elasticity and such a relation between the coefficients of thermal expansion of the materials that the changes in volume in the layers caused by temperature fluctuations during operation are absorbed by the elasticity of the materials so that the layers retain their adhesion to each other at the temperature fluctuations occurring during operation.

19. A device as claimed in claim 17 or claim 18, **characterized** in that the materials in said layers have high elasticity, preferably with an E-modulus less than 500 MPa, most preferably less than 200 MPa.

20. A device as claimed in any of claims 17-19, **characterized** in that the coefficients of thermal expansion for the materials in said layers are of substantially the same magnitude.

21. A device as claimed in any of claims 17-18, **characterized** in that the adhesion between the layers is of at least the same magnitude as in the weakest of the materials.

22. A device as claimed in any of claims 17-19, **characterized** in that each of the semiconducting layers essentially constitutes one equipotential surface.

23. A bracing device for use in a rotating electric machine according to any of claims 1-22, **characterized**

in that the bracing device includes the features of the bracing device of claim .

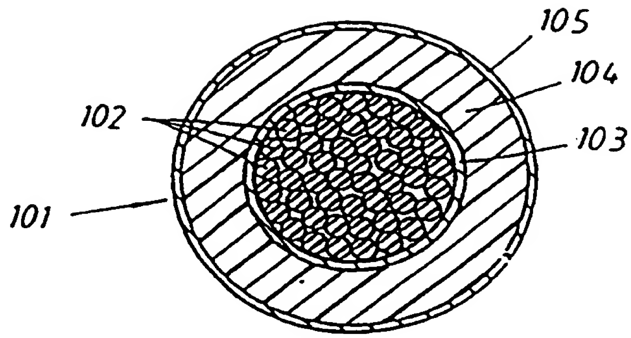

Fig. 1

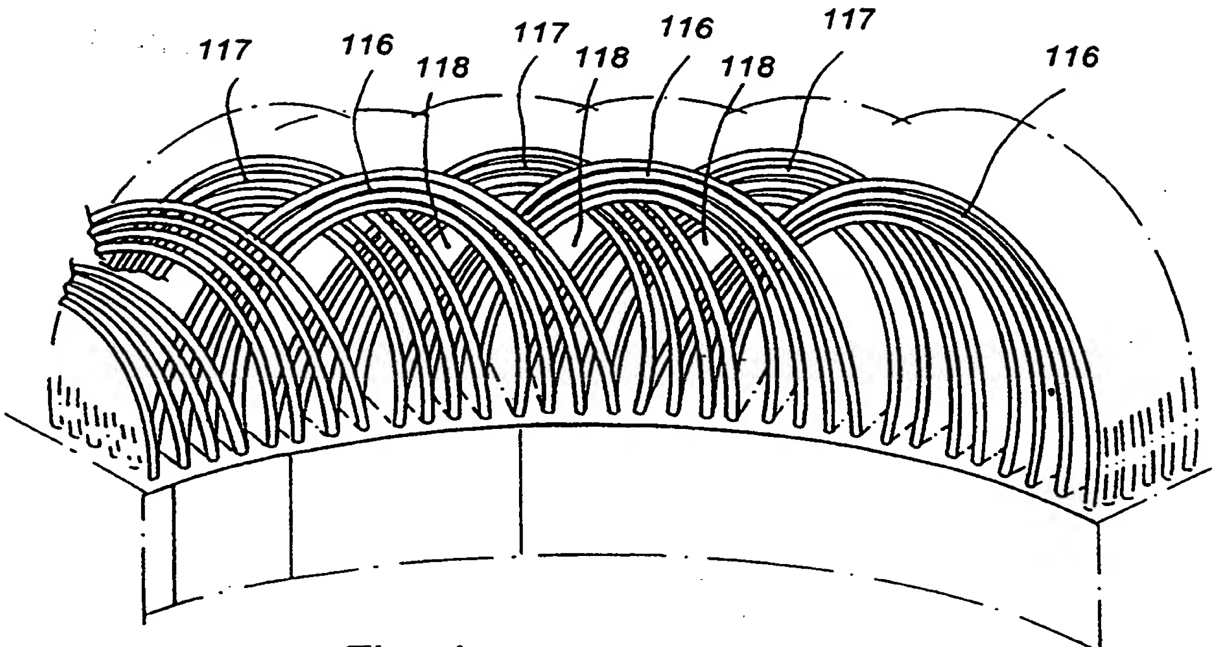

Fig. 4

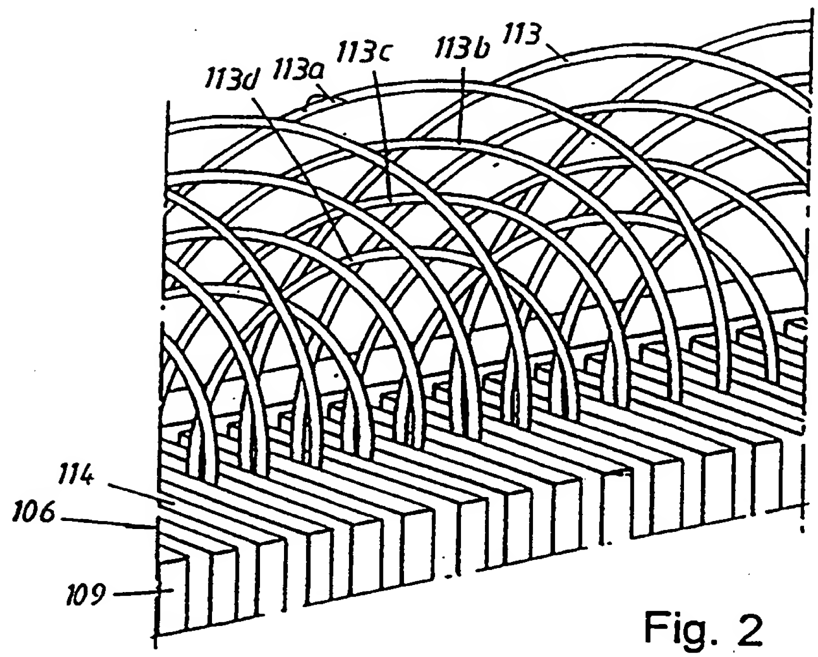
113d
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Fig. 2

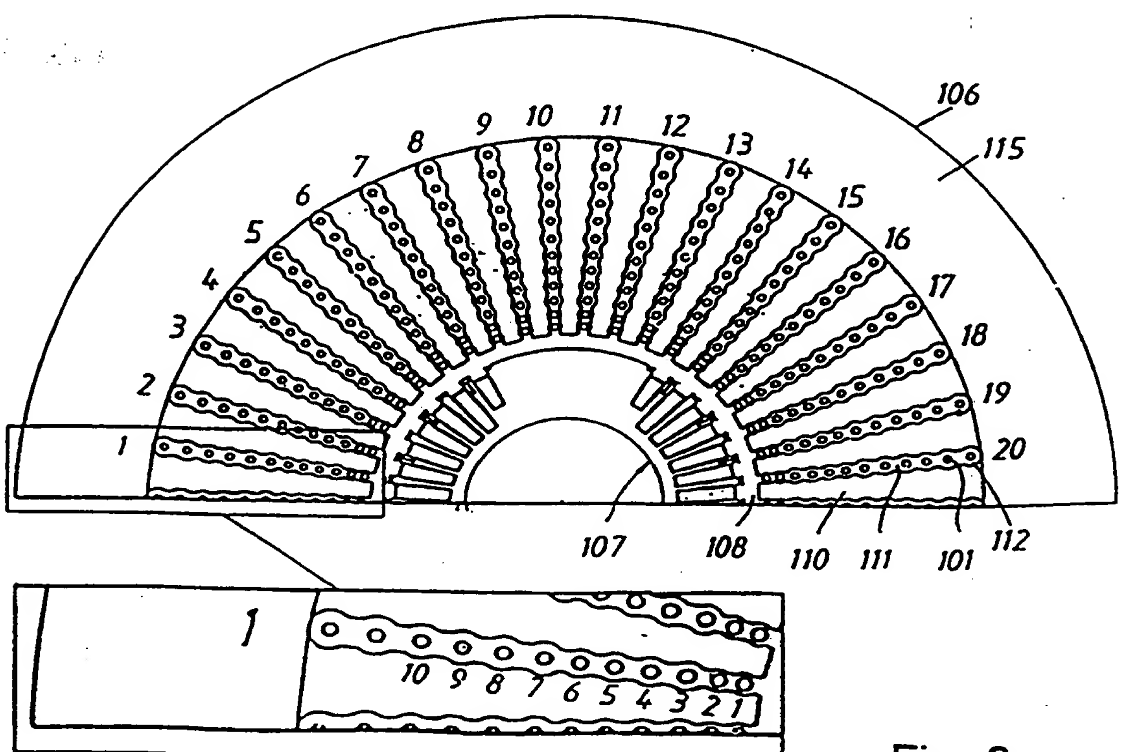
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Fig. 3

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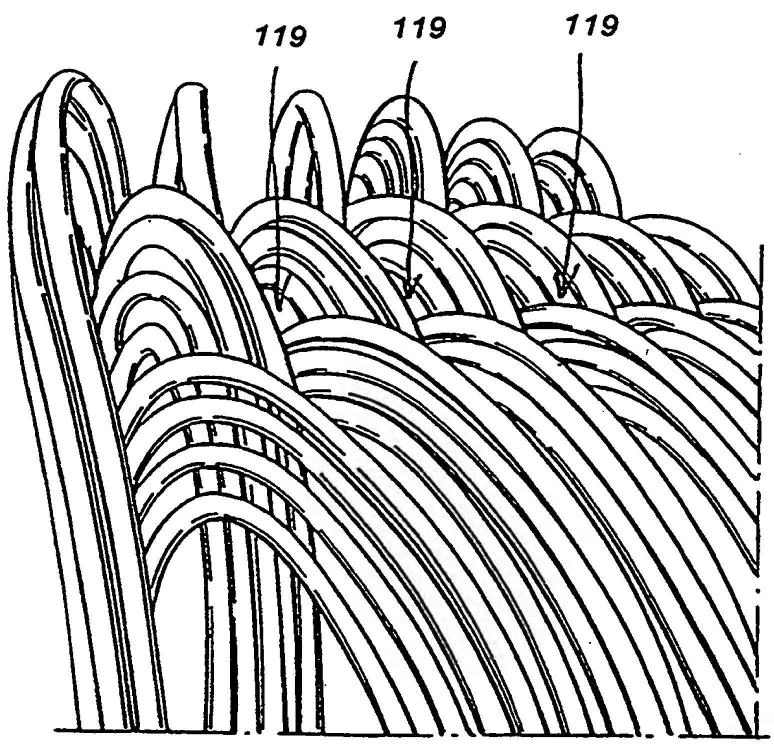

Fig. 5

Fig. 6

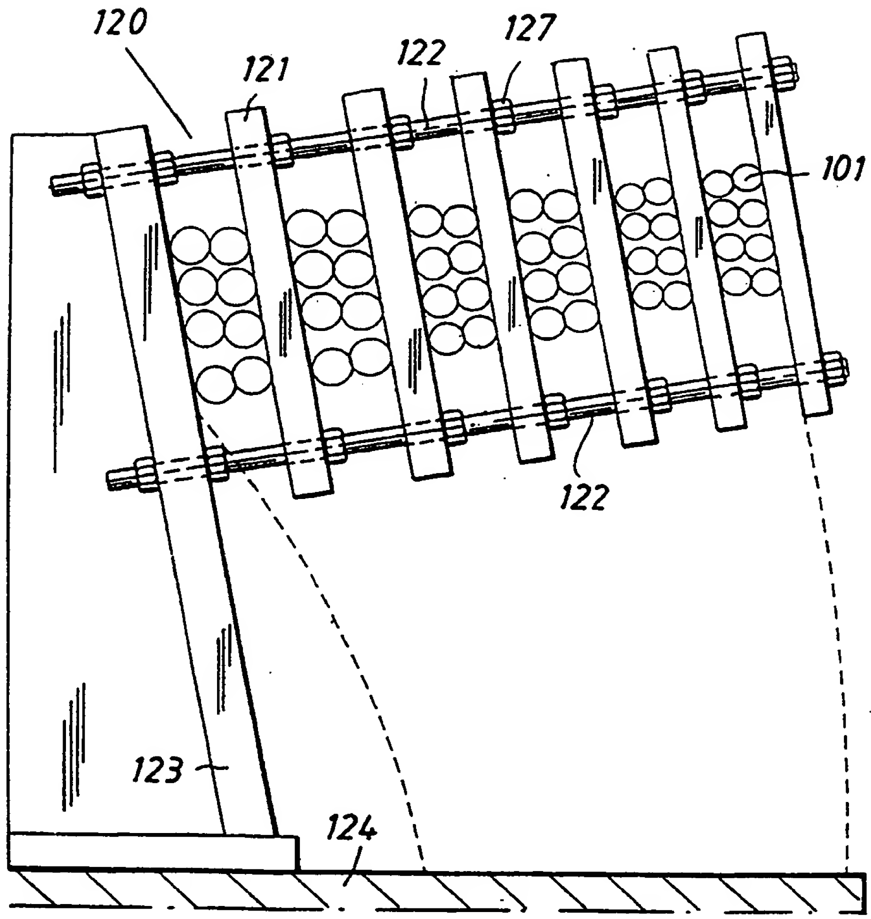

Fig. 7

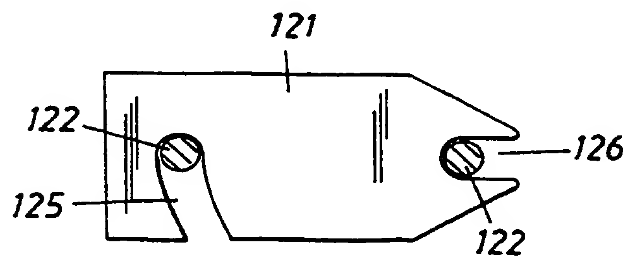

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Fig. 8

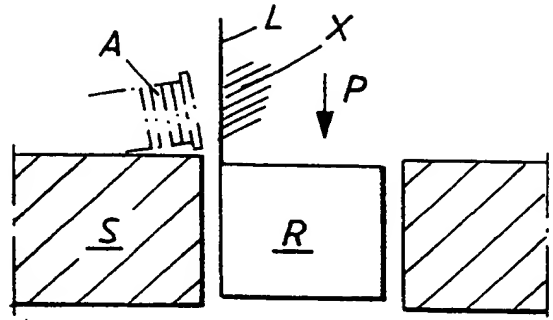
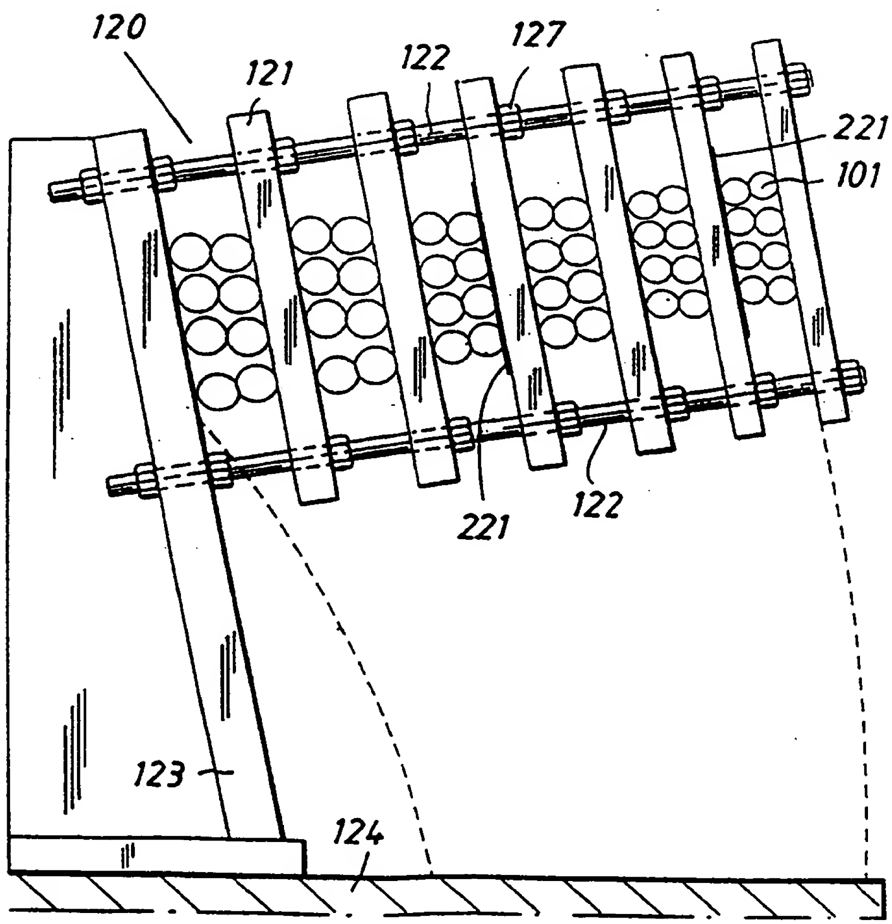


Fig. 9



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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00179

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 3/50, H02K 3/40, H02K 3/30
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5355046 A (K.WEIGELT), 11 October 1994 (11.10.94), column 5, line 2 - line 7; column 6, line 1 - line 13; column 7, line 1 - line 7, figure 1, col.71i.15-1i.22,col.71i.41 -1i.45,col.7, 1i.62-1i.63,col.8 lin.4-1i.5,col.8 1i.25-1i43,col 8 1i.57 1i.68	1-3
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A	US 5036165 A (R.K.ELTON ET AL), 30 July 1991 (30.07.91), column 1, line 16 - line 60; column 2, line 26 - line 57, figure 1, abstract	1-3
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 July 1998	21 -07- 1998
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Hans Bagge af Berga Telephone No. +46 8 782 25 00

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4510077 A (RICHARD K. ELTON), 9 April 1985 (09.04.85), column 1, line 41 - line 46; column 1, line 54 - line 57; column 1, line 62 - line 65, column 2, line 19 - line 20, column 3, line 37 - line 41, column 4, line 8 - line 18, column 8, line 21 - line 41, line 67 - line 68, column 5, line 1 - line 3, line 34 - line 40 --	1-3
A	US 5468916 A (M.LITENAS ET AL), 21 November 1995 (21.11.95), abstract --	1-3
A	WO 9406194 A1 (ELIN ENERGIEVERSORGUNG GESELLSCHAFT M.B.H.), 17 March 1994 (17.03.94), abstract --	1-3
A	US 4238339 A (G.M.KHUTORETSKY ET AL), 9 December 1980 (09.12.80), figure 1, abstract --	1-3
A	US 4488079 A (G.F.DAILEY ET AL), 11 December 1984 (11.12.84), figure 1, abstract -- -----	1-3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00179

Box I Observati ns where certain claims were found unsearchable (Continuation f item 1 of first sheet)

This internati nal search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 23
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

see extra sheet

3. ☒ Claims Nos.: 4-23
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest.
☐ N protest accompanied the payment of additi nal search fees.

According to PCT, Rule 6.4(a), first sentence, a dependent claim "shall then state the additional features claimed", after referring to one or more ther claims. Claim 23 does not state any additional features and is therefore considered unsearchable.

INTERNATIONAL SEARCH REPORT

Information on patent family members

30/06/98

International application No.
PCT/SE 98/00179

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